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A Novel Design and Fabrication of Multichannel Microfluidic Impedance Spectroscopy Sensor for Intensive Electromagnetic Environment Application

M.-P. Schmidt[a]*, A. Oseev[a], C. Engel[a], A. Brose[a], A. Aman[a], S. Hirsch[a]

[a]*Institute of Micro and Sensor Systems (IMOS)/ Otto-von-Guericke-University, Magdeburg, Germany*

Abstract

The article reports about the design and fabrication of a novel multichannel microfluidic sensor which is capable to be employed in intensive electromagnetic environment where sensors are required to stand against strong external electromagnetic field with interference-free measurement results. Most impedance spectroscopy sensors use planar electrodes. Here a multichannel sensor based on Silicon/SU8 is created with top/bottom electrode design. All the contact pads, as signals shield contacts, ground electrodes are positioned on the same chip side for flip-chip attachment by solder process. The sensor chip includes four fluidic channels to analyze multicomponent mixtures by simultaneous measurement at different frequencies.

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Keywords: Impedance Spectroscopy, Microfluidic Sensor, Ethanol Concentration Measurement, Flip Chip, Electromagnetic Shield, Silicon, SU8, SU8 bonding, SU8 adhesion, Process Monitoring

1. Introduction and Motivation

Multichannel microfluidic impedance spectroscopy sensor platform is a promising approach for multicomponent liquids analysis. Whereas most of currently developed microfluidic impedance spectroscopy sensors contain the system of planar electrodes, multichannel sensor requires an alternative approach which affords to overcome issues with neighboring channels field interference and is in principle foreign field protected [1-5].

* Marc-Peter Schmidt, Universitaetsplatz 2, 39106 Magdeburg. Tel.: +49 391 6751598; fax: +49 391 6712601.
E-mail address: marc-peter.schmidt@ovgu.de

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Microfluidic chip with a system of opposite electrodes provide an opportunity to create relatively small and highly sensitive multichannel sensor which is completely foreign field protected and is applicable for use in intensive electromagnetic environment. Advantages of opposite electrodes approach at the same time bring complexity in chip manufacturing where certain technological steps have to be fulfilled. Due to high demands to foreign field protection it is necessary to create a sensor chip with opposite electrodes design which is applicable for a single side attachment directly to PCB with BGA standard despite its double-side electrodes origin. Design and completed technology for such a multichannel microfluidic chip are demonstrated in current contribution.

2. Methods and Design

Silicon-Polymer based multichannel microfluidic sensor (20 mm x 55 mm) with a 3D electromagnetic shield, Fig. 1a), having one side contacting and able to be directly soldered to PCB or any measuring circuit has been developed and manufactured. To enable an adhesion process on one side a mechanical stabilization pad of the polymer under the connection area was included during the design process, Fig. 1b).

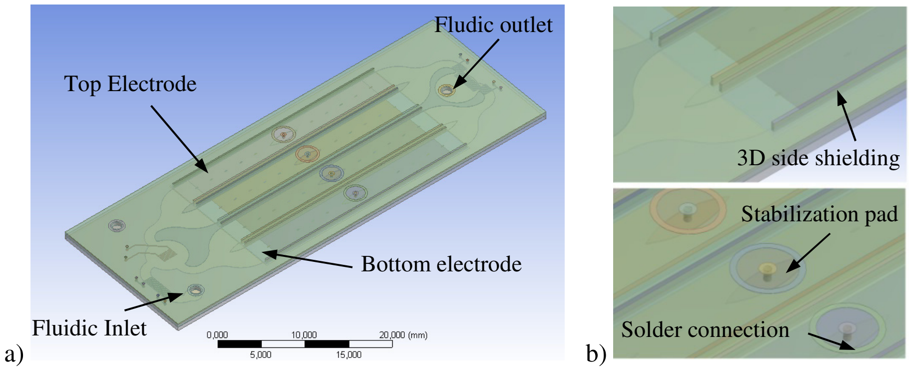

Fig. 1: Design concept of the multichannel microfluidic impedance spectroscopy sensor.

2.1. Design and Simulation

Design of the sensor chip was accomplished applying ANSYS 14.5 CFX for microfluidic simulations and Comsol Multiphysics 4.3b for electrodes design and electromagnetic field simulation. An inlet pressure of 40 kPa and water as a fluid were used to stress the fluidic structures, Fig. 2. The fluid stream is evenly distributed in the sensor electrode area but a turbulent flow can be expected in the branching before and after that electrode area. The fluidic structure generates no pressure surges and prevents additional vapor generation which is important for a significant sensor signal.

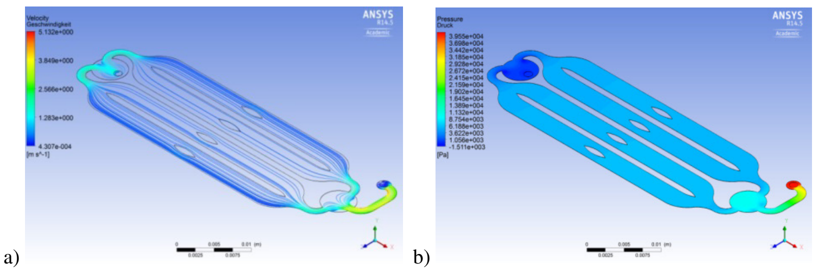

Fig. 2: Simulation of pressure and flow distribution in microfluidic chip with ANSYS 14.5 CFX.

Electrostatic simulations demonstrate uniform field distribution in electrodes area with sufficiently low field propagation in non-sensing area Fig. 3a). In order to provide reliable sensor response, we have to complete shielding the way which affords to minimize an influence of external field on sensor electrodes. For this reason sensor has to demonstrate considerable level of electrostatic field decay in open areas where foreign field (the same way as sensor electrodes field) is valuably suppressed by grounded shielding electrodes. Analysis of electrostatic field intensity has been completed for the sensor model which is identical in geometry and material of fabricated one Fig. 3b) and field distribution has been analyzed in directions across channels Fig. 3c) and along one of the channels Fig. 3d). The simulation model shows that designed sensor provide more than sufficient level of shielding that makes it applicable for intensive external field environment.

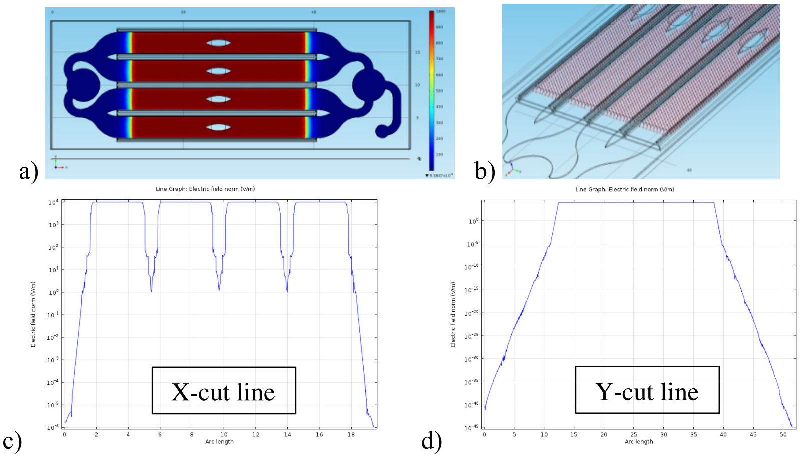

Fig. 3: Simulation of electrostatic field distribution with COMSOL 4.3b: a) electrostatic field distribution in microfluidic chip; b) simulation model; c) electrostatic field intensity distribution across the channels; d) electrostatic field intensity distribution along the channels.

2.2. Sensor fabrication

The fabrication process was divided into three parts, Fig. 4a). First the fabrication started with the cleaning of the 4” undoped silicon wafer with an HF 1 % dip for 1 min. For the bottom electrode a 330 nm layer of Titanium (Ti) and Platinum (Pt) was sputtered and structured via a lithography and wet chemical etching steps. After the stripping of the lithography mask a 50 µm thick SU8-50 layer was spin coated and structured to implement the microfluidic channels.

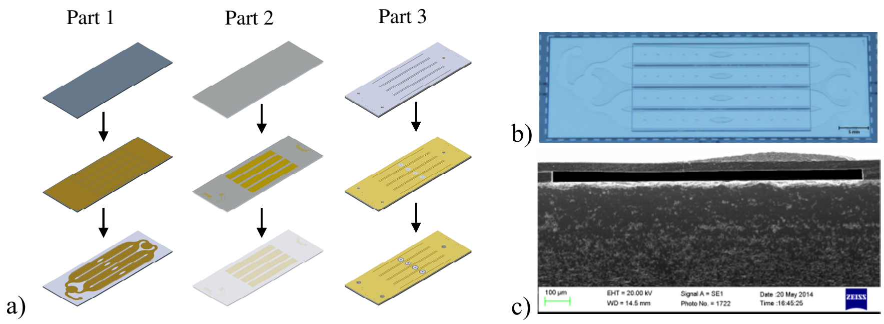

Fig. 4: Fabrication process a), completed sensor b) and microfluidic channel SEM image c)

Second cap Borosilicate glass wafer was cleaned with a piranha etch and coated with a 3 µm thin adhesion promoter, Omnicoat, to improve the adhesion of the next 50 µm thick layer of SU8-50. A second 300 nm structured Platinum layer was used to establish the top electrode on the cap wafer. The layer was covered by 5 µm of SU8-5. Both wafers were bonded with an assistance of a SUSS MA6/BA6 and a SUSS SB6e Substrate Bonder. After the bonding process the glass wafer was separated from the sandwich by a releasing step of the Omnicoat.

Third a 200 nm layer of structured Aluminum (Al) was used to mask the SU8 for a plasma etching step in an Oxford Instruments PlasmaSystem100. To prevent any thermal mechanical damages of the SU8 layers during the etching process the package was backside cooled with helium and etched in steps of 30 sec with a mixture of SF_6/O_2 to open the top sensor electrode contact and the sidewalls for the shielding. The Al was stripped and a new metal layer of 30 nm Pt and 500 nm Al were deposited with a Lift-Off process to connect the top electrodes and establish the 3D-shielding. To realize the solder connections a final photoresist Ti Spray was spray coated with a SUSS Delta Altaspray. An electroless metallization bath was finally used to plate the nickel and gold solder structures.

3. Results and discussion

In order to provide one side chip connection with possibility for Flip-Chip Assembly, technological steps have been defined in order to achieve a prescribed result. Number of technological issues has been resolved in order to produce the final novel multichannel sensor chip such as SU8-metal adhesion issues, establishing of appropriate bonding process, releasing of sensor structure and plating process in conjunction with standard MEMS technology.

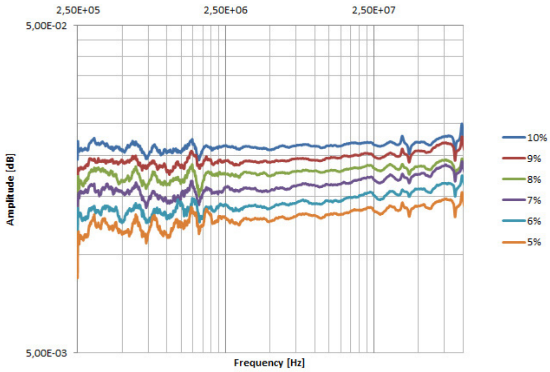

Fig. 5: Sensor S_{21} parameter measurement of a mixture of water and ethanol in a frequency range of 0,25 MHz and 250 MHz

Results of completed technological steps and experimental setup are demonstrated in Fig. 4b), c). The Sensor was soldered on an active pre-coupling electronic and measured with an FPGA based NWA both self-developed [6]. Furthermore the fluidic inlet/outlet connections were attached to a microfluidic pumping system containing a piezoelectric micro pump from TAKASAGO ELECTRIC INC and an external reservoir. To eliminate the temperature influence of the sensor signal the system was tempered to a constant temperature of 30 °C. Experimental investigations of the microfluidic sensor with a mixture of DI-water and Ethanol (5-10 Vol%) showed a significant correlation between measured S_{21} parameters and ethanol concentration in a frequency range of 0,25 MHz to 250 MHz, Fig. 5.

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